Textural and Mineralogical Characteristics of Tills of Northeastern and North-Central Ohio[1]

John P. Szabo, Department of Geology, University of Akron, Akron, OH 44325-4101

Abstract. **Textural and mineralogical parameters of over 3400 till samples are summarized to provide a database for scientists and engineers working with fractured tills in Ohio. Matrix textures (% <2.0 mm), carbonate contents (% <0.074 mm), and diffraction intensity ratios (illite/chlorite + kaolinite) were commonly measured. Texturally, most tills become sandier and less clay rich as they are traced onto the Allegheny Plateau. The overall distribution of mean textures of the Illinoian tills is similar to that of the Late Wisconsinan tills. Incorporation of local clastic bedrock on the plateau or changes in mode of deposition may be the reason for increased sand content. Carbonate contents of tills are generally larger in the Lake and Till plains provinces, and carbonate contents decline along transects from the Till Plains to the Allegheny Plateau. Exceptions to this trend are caused by the release of far-traveled carbonates from the englacial load of glaciers during formation of end moraines. Similarly the lithology of the sand fraction (1.0-2.0 mm) reflects the underlying bedrock, but proportions of igneous and metamorphic rock fragments increase within end moraines where englacial load is released. Diffraction intensity ratios decrease onto the plateau because of the entrainment of Pennsylvanian-age shales containing kaolinite. Numerous factors such as glacier dynamics, topography of the underlying bedrock, bedrock lithology, amount of bedrock exposure, and dilution by older glacial deposits affect the texture and composition of tills. Future research should examine the possible relation of texture and mineralogy to joint width.**

OHIO J SCI 106 (2):9-16, 2006

INTRODUCTION

Pleistocene geologists have recorded the presence of fractures in outcrops and exposures of tills of northeastern and north-central Ohio since Read (1880) first described them. Fractures occur in tills throughout the glaciated part of Ohio (Brockman and Szabo 2000). Oxidation and related cementation along fractures have penetrated laterally 2.0 cm into gray, unaltered Illinoian tills exposed in tributaries to the Cuyahoga River. Secondary iron, which acts as a cement, has accumulated to the extent that some fractures stand out in relief when compared to the unweathered matrix of the tills (Szabo 1987). Thin coatings of light gray, calcareous silt often veneer joint planes in oxidized zones of Wisconsinan tills (Szabo and Ryan 1980; Fausey and others 2000). In northeastern Ohio this phenomenon frequently occurs in exposures of the Late Wisconsinan Hayesville Till, and additional movement of water along fractures is indicated by the formation of authigenic gypsum crystals up to 4.0 cm in length, 4.0 m beneath the surface. Gypsum crystals are found at the boundary between oxidized brown till and unoxidized gray till on uplands in Summit County (Fig. 1). Other occurrences of gypsum crystals at contacts between calcareous Wisconsinan tills and underlying lacustrine units (Bain 1990) suggest that geochemical conditions changed as groundwater flow was affected by differences in hydraulic conductivity. All these features suggest that water flows through clay-rich units along fractures and eventually recharges underlying aquifers.

The purpose of this paper is to present a summary of textural and mineralogical characteristics of fractured tills found in northeastern and north-central Ohio that can be used as a database by scientists and engineers working with tills. Discussion of the database and its relation to physiographic provinces (Fig. 2a) and glacial processes may explain variations within tills at specific field sites. Correlations of units found on the Allegheny Plateau (White 1982; Szabo and Totten 1995) are summarized in Table 1. Correlations of Illinoian tills of the Scioto lobe (Fig. 2b), especially those units in the Lake Plain and Till Plains physiographic provinces, are very tenuous and have been made based on descriptions and lithologic character.

MATERIALS AND METHODS

Samples used in this summary were collected from outcrops or from cores in 21 counties (Fig. 1). Texture, Munsell color, consistency, structure, reaction to dilute HCl, and the nature of lithologic contacts were recorded in field notes. Matrix textures (% <2.0 mm) of the samples were determined using settling and pipetting methods of Folk (1974). In this study the sand-silt break is 0.063 mm, and silt-clay break is 4.0 μ. The carbonate content (% <0.074 mm) was determined using a Chittick apparatus (Dreimanis 1962); this grain size was used because it contains the terminal grades of calcite and dolomite and can be related to provenance of tills. A terminal grade is the smallest grain size to which an entrained clast may be reduced by crushing and abrasion under a glacier. The terminal grade varies among minerals and is dependent on the mineralogical properties and available energy at the base of the glacier. Diffraction intensity ratios (DIs) of the clay fraction (<2.0 μ) were calculated by measuring the area under the illite peak at 1.0 nm and dividing it by the area under the kaolinite

[1]Manuscript received 15 October 2002 and in revised form 20 May 2003 (#02-02F).

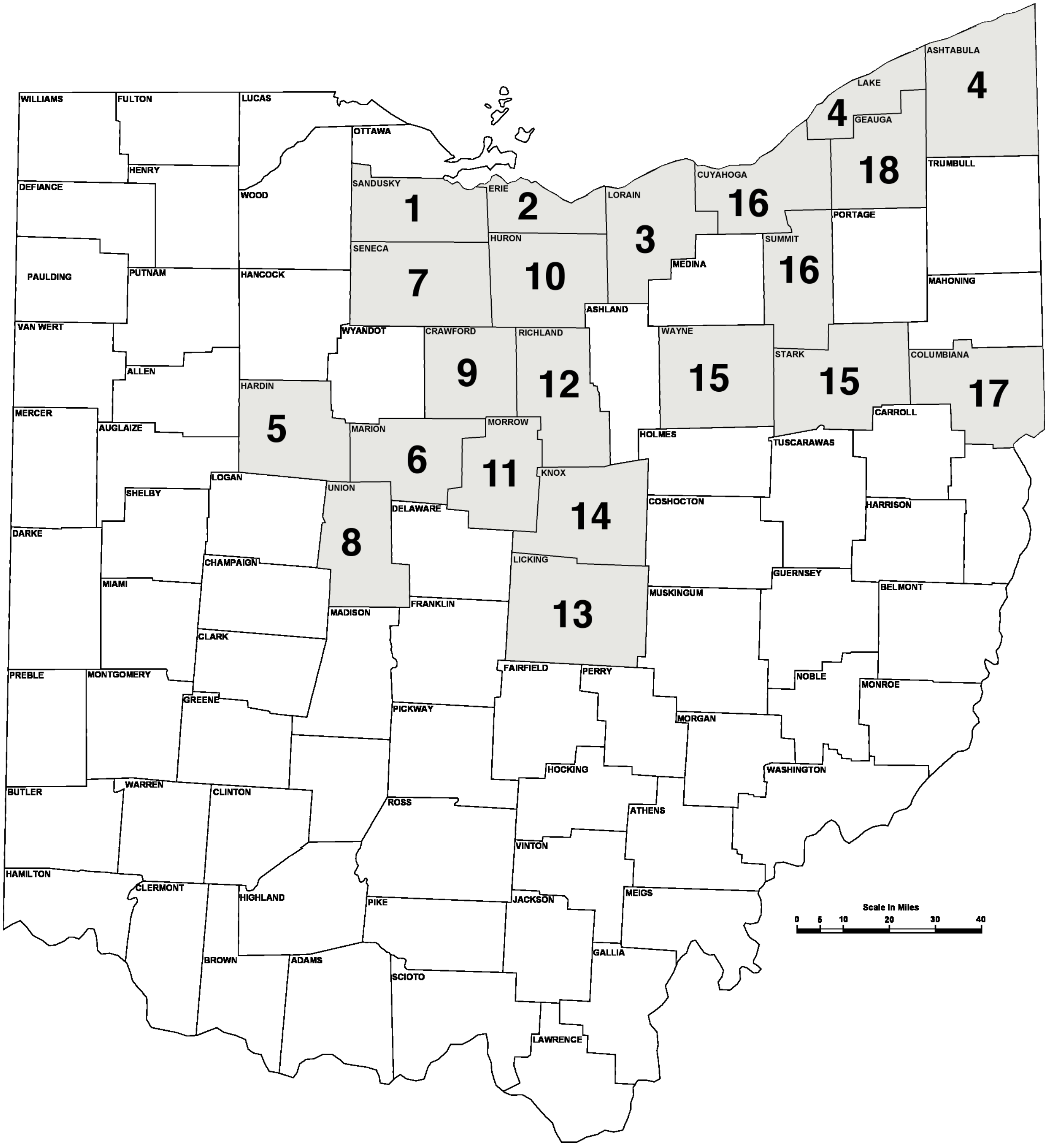
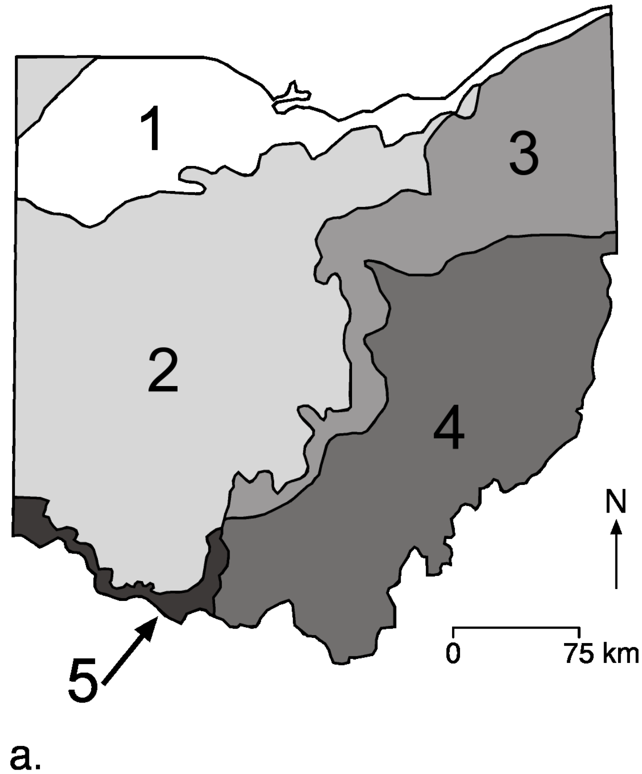


FIGURE 1. Locations and sources of data for this summary. 1. Angle (1987), 2. Hofer and Szabo (1993), 3. Totten (1989), 4. Szabo and Bruno (1997), 5. Totten (1988a), 6. Totten (1986), 7. Fernandez (1986), 8. Angle (1991), 9. Totten (1987), 10. Totten (1985a), 11. Totten (1985b), 12. Totten (1973), 13. Frolking and Szabo (1998), 14. Viani (1986), 15. Storck and Szabo (1991), 16. Szabo (1987), 17. Volpi and Szabo (1988), and 18. Totten (1988b).

and chlorite peak at 0.7 nm (Willman and others 1966; Bruno and others 2006). Two other parameters were occasionally measured in research on which this paper is based. The lithology of the 1.0-2.0 mm-sand fraction is representative of the clast content of tills (Anderson 1957). Ratios of quartz to feldspar in the 0.250-0.125 mm-sand fractions are suggestive of the amount of local sandstone incorporated into the ice (Gross 1967).

Members of the Department of Geology at the University of Akron have performed laboratory analyses on approximately 8000 samples of glacial sediments over the past 25 years. Data from 3415 samples from the University of Akron, from published articles, and from unpublished reports of the Ohio Division of Geological



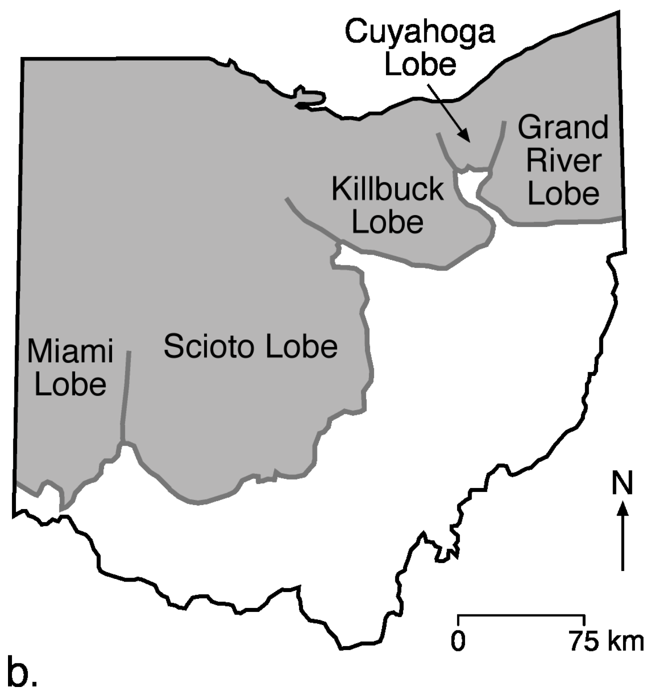


FIGURE 2. Flow paths of glacial lobes were influenced by the physiography of Ohio. a. Generalized physiographic regions of Ohio (modified from Brockman 1998). 1. Huron-Erie Lake Plains, 2. Till Plains, 3. Glaciated Allegheny Plateaus, 4. Allegheny Plateaus, 5. Bluegrass Section. b. Distribution of glacial lobes in Ohio.

Survey are summarized in Table 2. Data for the 1.0-2.0 mm-sand lithology and quartz-feldspar ratios are not included in the table because of the small number of analyzed samples. Descriptive statistics from individual studies were combined to calculate the grand means and total number of samples for till units in each physiographic province. Because not all sources provided standard deviations or variances, combined variances or standard deviations could not be calculated. Some standard deviations for combined data are available from the author.

RESULTS

The non-uniform number of samples of each till in each physiographic province (Table 2) and the lack of occurrences of some tills in these provinces makes interpretation of the summary table difficult. Texturally, most tills become sandier and less clay rich as they are traced onto the plateau. This trend is illustrated by samples of the Navarre Till in which sand increases from a mean of 20% in the Till Plains to one of 34% on the Allegheny Plateau. Clay content declines from 30% to 23%. The Hayesville and Northampton tills are exceptions to this trend (Table 2); they both exhibit increases in clay content and decreases in sand content. Data sets for these tills are biased by the large number of samples from the Cuyahoga Valley where the Northampton Till overlies clay-rich lacustrine deposits and soft shale and is overlain by Hayesville Till (Szabo 1987).

Carbonate contents tend to decline along transects from the Lake Plain onto the Allegheny Plateau. Calcite contents decrease during this transition across physiographic provinces, but dolomite contents remains similar. The Illinoian Millbrook Till and its equivalents (Table 1) are readily traceable because of their lack of calcite and their consistent dolomite contents (Table 2); they can be used as a regional marker bed. In a similar fashion, examination of their respective proportions of calcite compared to dolomite may separate the Wisconsinan Hiram and Hayesville tills, which have nearly identical field characteristics in the Lake Plain. The Hiram Till often contains more calcite than dolomite, whereas the Hayesville Till contains about equal proportions of those minerals (Table 2). The consistent proportion of calcite to dolomite in the Illinoian Northampton Till appears to be an identifying characteristic of that till.

Where enough data are available, DIs (diffraction intensity ratios) for some units decrease on the plateau. The validity of the use of this parameter is controlled by the degree of weathering in the tills. The calculation of consistent and reliable DIs requires that the samples be from exposures of unoxidized till. Chlorite alters to vermiculite before calcite begins to leach (Willman and others 1966); thus, any oxidation of the till in the exposure could lead to erroneous calculations of DI. Samples in the data set (Table 2) are only from unweathered gray samples. Many samples collected from younger Wisconsinan tills were oxidized brown throughout their thicknesses and could not be used for comparisons among physiographic provinces. Older Illinoian tills exposed through recent erosion by streams in deep valleys or by excavations for landfills provided reliable measures of DI.

Table 1

Tentative correlation of lithologic units in north-central and northeastern Ohio. Locations of lobes are shown in Figure 2b.

Time	Scioto Lobe Western	Scioto Lobe Eastern	Scioto Lobe Northern	Killbuck Lobe	Cuyahoga Lobe	Grand River Lobe
						Ashtabula Till
Late Wisconsinan	Hiram Till	Hiram Till	Hiram Till	Hiram Till	Hiram Till	Hiram Till
	Hayesville Till	Hayesville Till	Hayesville Till	Hayesville Till	Lavery Till	Lavery Till
	Navarre Till	Navarre Till	Navarre Till	Navarre Till	Kent Till	Kent Till
Middle Wisconsinan through Sangamonian						
		Millbrook till U	Millbrook till U			
	"young" till	Northampton Till	Millbrook till M	Northampton Till	Northampton Till	not found
Illinoian	"older" till	Millbrook Till	Millbrook till L	Millbrook Till	Mogadore Till	Titusville Till
	"oldest" till	Gahanna Till				Keefus Till
		Chesterville Till				

DISCUSSION

The texture and composition of tills are affected by numerous factors such as glacier dynamics, topography of the underlying bedrock, bedrock lithology, amount of bedrock exposure, and dilution by older glacial deposits (Clark 1987; Szabo and Totten 1992). Within the area covered in this summary, the Allegheny Escarpment marks a transition along which the bedrock surface rises from the lowlands of the Till Plains to the higher elevations of the Allegheny Plateau (Fig. 3). Locally this escarpment affected subglacial processes responsible for the composition of tills (Szabo and Totten 1992). Brockman and Szabo (2000) concluded that fractures in tills of the Allegheny Plateau are more frequent than in tills within the Till Plains because, as ice flowed around resistant bedrock knobs on the plateau, local stresses at the base of the ice produced shears in underlying older tills.

The distribution of mean matrix textures of tills as shown on ternary diagrams (Fig.4) is similar to the range of matrix textures plotted on a similar diagram in Tornes and others (2000). The distribution of values for the Wisconsinan tills (Fig. 4a) is comparable to the Illinoian tills (Fig. 4b). In most cases values derived from samples taken from the plateau or escarpment areas are shifted toward the sand apex of the ternary plot, whereas values from samples taken from the till and lake plains contain less sand and are displaced towards the clay apex. Some deviations from these observations do occur. The Northampton Till from the plateau is skewed towards the clay apex because of its association with lacustrine sediments in the Cuyahoga valley, and the Late Wisconsinan Navarre Till from all provinces is sandier than the younger tills (Table 2, Fig. 4a).

The matrix textures of most units become sandier for two possible reasons. First, the underlying bedrock changes from carbonates and shales of the Till Plains to sandstones and conglomerates of the Allegheny Plateau. Examination of the 1.0-2.0 mm-sand fraction of tills (Viani 1986) showed a strong local bedrock component in the tills on the plateau. Secondly, some of the tills on the plateau were deposited as subglacial or supraglacial meltout deposits; meltwater may have removed some of the fines producing sandy tills (Fig. 3).

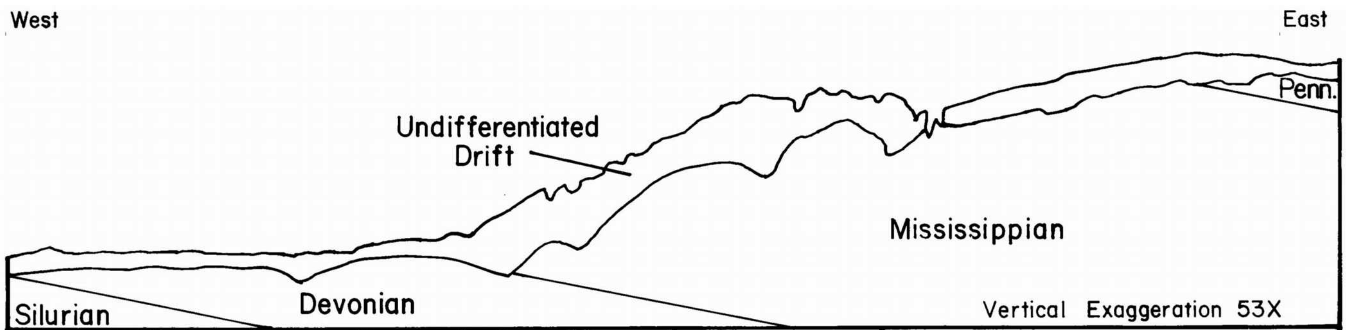
Generally the carbonate contents of tills decline from the Till Plains to the Allegheny Plateau because of dilution through the incorporation of noncalcareous clastic rocks along the flow path. Figure 5a shows that samples from late Wisconsinan tills from the Lake Plains and Till Plains have larger calcite and dolomite contents than those from the same units sampled on the escarpment or the plateau. Szabo and Totten (1992) showed some exceptions to the trend illustrated by the Hayesville Till on the plateau (HY-P, Fig. 5a). They demonstrated that at locations along the escarpment normal to ice flow, englacial ice containing carbonate-rich debris was reactivated to become basal ice on the plateau and served as a mechanism responsible for some tills having a carbonate content greater than expected (Fig. 3). Additionally, supraglacial meltout deposits of the Navarre Till derived from englacial ice contain more carbonate than subglacial deposits derived from the basal ice that had been diluted by older deposits (Frolking and Szabo 1998). Although there is some variation among lithofacies of tills, the greatest variation generally occurs within the supraglacial deposits (Szabo and Bruno 1997; Brockman and Szabo 2000). The Illinoian Northampton and upper Millbrook tills follow the same general trend as the Late Wisconsinan tills (Fig. 5b). Among the other Illinoian tills, only the Millbrook Till occurs in all four provinces, and the samples of it from the Till Plains have larger dolomite contents than those from other provinces. The point representing this till in the Lake Plains (Fig. 5b) comes from only one sample because this unit generally has

TABLE 2

Summary of laboratory data for lithologic units found in north-central and northeastern Ohio. A more extensive table, in which data are classified by individual study including variances where published, is available from the author.

Unit Location	Sand * % <2.0 mm	Silt * % <2.0 mm	Clay * % <2.0 mm	Calcite % <0.074 mm	Dolomite % <0.074 mm	Total Carb % <0.074 mm	DI <2.0 μ
Ashtabula Till							
Lake Plain	16/233 **	53/233	31/233	2.2/194	5.6/194	7.8/194	1.3/180
Hiram Till							
Lake Plain	13/29	42/29	45/29	11.5/22	7.0/22	18.5/22	n.a.†
Till Plain	15/173	40/173	45/173	4.6/84	7.8/84	14.0/112	n.a.
Escarpment	19/19	48/19	33/19	2.8/19	7.4/19	10.2/19	n.a.
Plateau	18/6	47/6	35/6	4.5/6	4.9/6	9.4/6	n.a.
Hayesville Till							
Lake Plain	19/89	42/89	39/89	9.0/73	8.1/73	17.1/73	1.8/14
Till Plain	19/492	43/492	38/492	7.2/387	9.5/387	17.4/478	1.9/36
Escarpment	24/94	45/94	31/94	2.8/95	8.1/95	11.1/95	n.a.
Plateau	0013	48/82	41/82	8.1/82	7.3/82	15.4/82	n.a.
Navarre Till							
Lake Plain	20/12	50/12	30/12	6.1/12	5.0/12	11.1/12	n.a.
Till Plain	26/322	43/322	31/322	5.9/314	11.1/314	17.4/322	1.9/10
Escarpment	28/126	44/126	28/126	1.9/126	7.7/126	9.6/126	1.3/3
Plateau	34/254	43/254	23/254	1.4/183	7.2/183	8.6/183	1.6/101
Millbrook till U							
Lake Plain	23/81	42/81	35/81	10.3/73	8.7/73	19.0/73	n.a.
Till Plain	21/132	43/132	36/132	7.8/86	8.5/86	15.7/133	n.a.
Northampton Till							
Lake Plain	18/15	48/15	34/15	6.1/15	8.1/15	14.2/15	n.a.
Till Plain	19/96	46/96	35/96	6.0/85	9.6/85	16.0/92	1.4/29
Escarpment	30/20	41/20	29/20	5.5/20	9.9/20	15.4/20	n.a.
Plateau	10/445	48/445	42/445	3.5/450	6.6/450	10.1/450	1.5/87
Millbrook Till							
Lake Plain	28/5	49/5	23/5	0/1	4.2/1	4.2/1	1.5/1
Till Plain	28/44	44/44	28/44	0.3/44	6.6/44	6.9/44	n.a.
Escarpment	31/81	45/81	24/81	0.1/85	4.8/85	4.9/85	1.4/20
Plateau	34/265	45/265	21/265	0.3/216	4.1/216	4.4/216	0.9/216
Gahanna Till							
Escarpment	33/19	43/19	24/19	4.5/19	15.2/19	19.7/19	1.2/8
Plateau	34/105	44/105	22/105	3.4/105	11.6/105	15.0/105	1.2/102
Chesterville Till							
Escarpment	34/32	45/32	21/32	1.4/32	9.0/32	10.4/32	1.0/20
Plateau	33/148	43/148	24/148	1.3/137	9.2/137	10.5/137	1.5/101

* Percentages of sand, silt, and clay are based on matrix weights after gravel was removed.
** Numerical sequence is mean/number of samples.
† n.a. = not analyzed.



Parameter	Till Plains	Allegheny Escarpment	Allegheny Plateau	Interpretation
Matrix Texture	Clayey	Sandier	Sandy	Incorporation of sandstone bedrock.
CO_3 Content	High	Low	Mod.-High	Dilution by bedrock & older drift over the escarpment.
Quartz/Feldspar	High	Low	Moderate	Quartz decreases over escarpment but increases over sandstone bedrock.
Dominant Clasts	CO_3	Shale	Sandstone	Erosion of local bedrock & comminution of extralocal bedrock.
Abundance of Ig. & Meta. Clasts	Low	Low	Higher	Comminution of far-traveled clasts to sand size.
$\frac{\text{Illite}}{\text{Kao.} + \text{Chlor.}}$	Constant	Constant	Lower	Dilution of regional bedrock composition by local bedrock.

FIGURE 3. Summary of changes in texture and composition along a hypothetical west-east transect from the Till Plains to the Glaciated Allegheny Plateau. CO_3 = carbonate, Ig. = igneous, Meta. = metamorphic, Kao. = Kaolinite, Chlor. = chlorite, Mod. = Moderate.

been eroded away by younger ice advances.

Changes in clay mineralogy generally reflect a regional change in the underlying bedrock. Within a given unaltered till unit, DIs display a remarkable lack of variation and may represent some process of homogenization of fine particles during glacial transport. The general decrease in DIs from the Till Plains onto the Allegheny Plateau (Fig. 3) results from a change in the underlying bedrock. Paleozoic shales of the Till Plains contain more illite and chlorite than kaolinite, whereas Pennsylvanian shales or underclays of the plateau contain a larger proportion of kaolinite (Volpi and Szabo 1988). The incorporation of these shales into tills of the plateau lessens the DIs (Fig. 3) by increasing the kaolinite component in the denominator of the DI. Another factor, as yet unquantified, is the effect of the incorporation of weathered older glacial deposits into younger tills. Weathered tills should contain kaolinite and expandable clay minerals. These also may be responsible for some of the variation in DIs either in the Till Plains or on the Allegheny Plateau.

Other parameters, measured in isolated studies (Viani 1986; Szabo and Ryan 1980), show some very general trends. Quartz to feldspar ratios are larger in the Till Plains than over the Allegheny Escarpment or the Glaciated Allegheny Plateau. The higher values in the Till Plains are perplexing because of the carbonate bedrock, but possibly the source of increased quartz could be incorporation of alluvium or preglacial outwash deposits. The moderate values on the plateau (Gross 1967) suggest erosion of the sandstone underlying higher parts of the plateau (Fig. 3). The lithology of the very coarse-sand fraction definitely reflects the composition of the underlying bedrock. The apparent increase in igneous and metamorphic rock fragments produced over the long transport distance to the plateau occurs in samples taken from end moraines where the englacial load of the ice was released. These rock fragments were entrained in Canada, lifted above the bed of the glacier, and transported in the englacial zone. As the ice stagnated, rock fragments in the englacial zone were released as the ice melted.

Descriptions of the outcrops and exposures from which samples were collected to compile the statistics for this study generally note the occurrence of fractures within the glacial sediments. These fractures are often noted because they either are iron stained or contain precipitated secondary minerals. Although fractures appear to be ubiquitous and independent of the matrix grain size, carbonate mineralogy, clay mineralogy, and possibly age, many questions still remain. The influence of these parameters upon fracture width needs consideration. Do both the clay content and the type of clay minerals in the tills affect the width or type of fracture? Does leaching along fractures produce a larger fracture width in tills having large carbonate contents than in those having lesser carbonate contents? Understanding the controls on fracture width is essential in determining the regional significance of fractures and subsequently the vertical hydraulic conductivity of tills and the movement of pollutants.

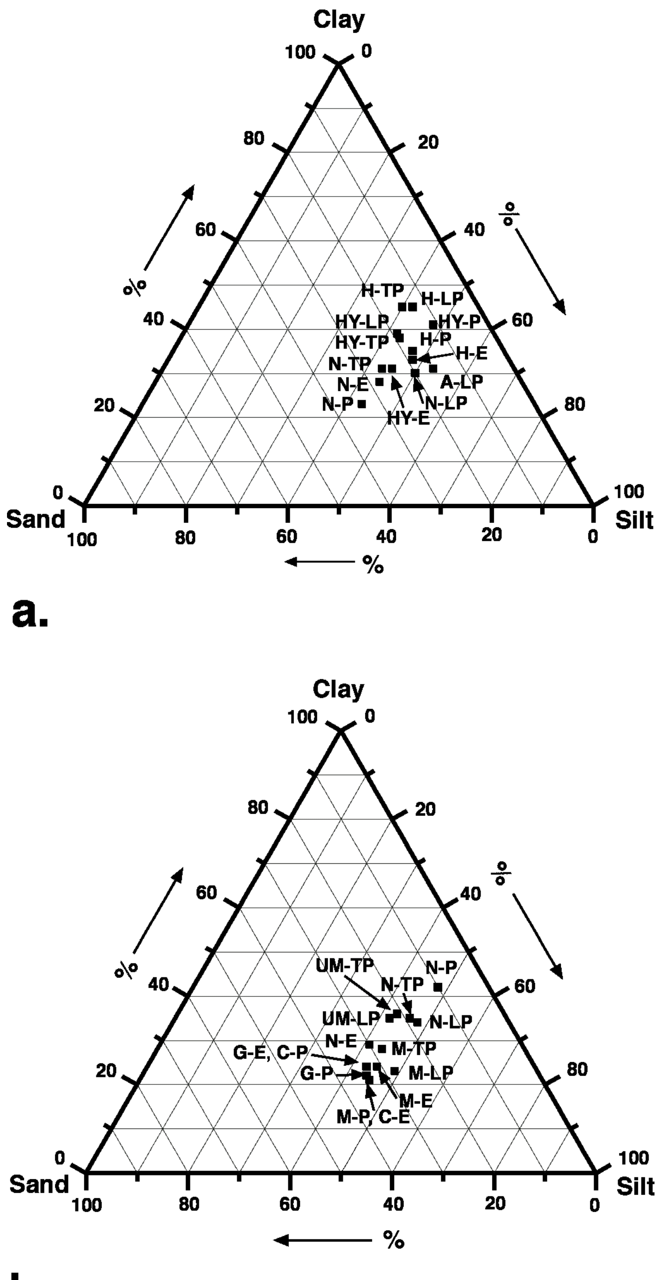


FIGURE 4. Ternary plots of mean matrix textures (% <2.0 mm) for samples from the four physiographic provinces: LP = Lake Plains, TP = Till Plains, E = Escarpment, P = Plateau. a. Late Wisconsinan tills: A = Ashtabula, H = Hiram, HY = Hayesville, N = Navarre. b. Illinoian tills: MU = upper Millbrook, N = Northampton, M = Millbrook, G = Gahanna, C = Chesterville.

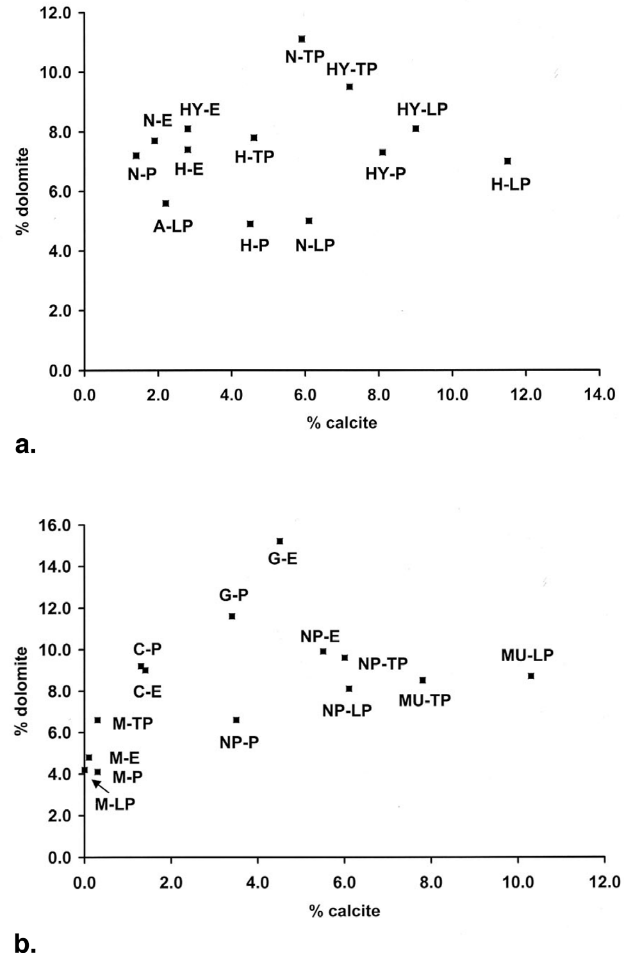


FIGURE 5. Plots of mean calcite content versus mean dolomite content (% <0.074 mm) for samples from the four physiographic provinces. Abbreviations are the same as those in Figure 4. a. Late Wisconsinan tills. b. Illinoian tills.

LITERATURE CITED

Anderson RC. 1957. Pebble and sand lithology of the major Wisconsin glacial lobes of the Central Lowland. Geological Society of America Bulletin 68:1415-50.

Angle MP. 1987. Glacial geology of Sandusky County, Ohio [Unpubl manuscript]. Available from: Ohio Div of Geological Survey, Columbus, OH.

Angle MP. 1991. Evolution of till stratigraphy in Union County, Ohio. Ohio J Sci 91:83-9.

Bain RG. 1990. Diagenetic, nonevaporative origin for gypsum. Geology 18:447-50.

Brockman CS. 1998. Physiographic regions of Ohio [map]. Available from: Ohio Div of Geological Survey, Columbus, OH.

Brockman CS, Szabo JP. 2000. Fractures and their distribution in the tills of Ohio. Ohio J Sci 100(3/4):39-55.

Bruno PW, Szabo JP, Foos A. 2006. Mineralogy of weathered Wisconsinan till along a fracture in the root zone. Ohio J Sci 106(2):17-21.

Clark PU. 1987. Subglacial sediment dispersal and till composition. J Geol 95:526-41.

Dreimanis A. 1962. Quantitative gasometric determination of calcite and dolomite by using a Chittick apparatus. J Sedimentary Petrology 32:520-9.

Fausey NR, Hall GF, Bigham JM, Alfred BJ, Christy AD. 2000. Properties of the fractured glacial till at the Madison County, Ohio, Field Workshop Pit Site. Ohio J Sci 100(3/4):107-12.

Fernandez RL. 1986. Glacial geology of Seneca County, Ohio [Unpubl manuscript]. Available from: Ohio Div of Geological Survey, Columbus, OH.

Folk RL. 1974. Petrology of sedimentary rocks. Austin (TX): Hemphill Publ Co. 182 p.

Frolking TA, Szabo JP. 1998. Quaternary geology along the eastern margin of the Scioto lobe in central Ohio. Columbus (OH): Ohio Div of Geological Survey Guidebook 16. 40 p.

Gross DL. 1967. Mineralogical gradations within the Titusville Till and associated tills of Northwestern Pennsylvania [Unpubl MS thesis]. Available from: Dept of Geology, Univ of Illinois, Urbana, IL. 207 p.

Hofer JW, Szabo JP. 1993. Port Bruce ice-flow directions based on heavy-mineral assemblages in tills from the south shore of Lake Erie in Ohio. Canadian J Earth Sciences 30:1236-41.

Read MC. 1880. Water supply of drift-clay lands of Ohio. Columbus (OH): Ohio State Board of Agriculture 34th Annual Report for the Year 1879. p 491-8.

Storck RJ, Szabo JP. 1991. Lithofacies and mineralogy of the late Wisconsinan Navarre Till in Stark and Wayne counties, Ohio. Ohio J Sci 91:90-7.

Szabo JP. 1987. Wisconsinan stratigraphy of the Cuyahoga Valley in the Erie basin, northeastern Ohio. Canadian J Earth Sciences 24:279-90.

Szabo JP, Ryan DE. 1980. Quaternary stratigraphy of the lower Mud Brook basin, Northampton Township, Summit County, Ohio. Ohio J Sci 83:38-44.

Szabo JP, Totten SM. 1992. Glacial dispersal rejuvenation on the Allegheny Plateau, north-central Ohio, based on till carbonate patterns. J Sedimentary Petrology 62:1044-53.

Szabo JP, Totten SM. 1995. Multiple pre-Wisconsinan glaciations along the northwestern edge of the Allegheny Plateau in Ohio and Pennsylvania. Canadian J Earth Sciences 32:2081-9.

Szabo JP, Bruno PW. 1997. Interpretation of lithofacies of the Ashtabula Till along the south shore of Lake Erie, northeastern Ohio. Canadian J Earth Sciences 34:66-75.

Tornes LA, Miller KE, Gerken JC, Smeck NE. 2000. Distribution of soils in Ohio that described with fractured substratums in unconsolidated materials. Ohio J Sci 100(3/4):56-62.

Totten SM. 1973. Glacial geology of Richland County, Ohio. Columbus (OH): Ohio Div of Geological Survey Report of Investigations 88. 55 p.

Totten SM. 1985a. Glacial geology of Huron County, Ohio [Unpubl manuscript]. Available from: Ohio Div of Geological Survey, Columbus, OH.

Totten SM. 1985b. Glacial geology of Morrow County, Ohio [Unpubl manuscript]. Available from: Ohio Div of Geological Survey, Columbus, OH.

Totten SM. 1986. Glacial geology of Marion County, Ohio [Unpubl manuscript]. Available from: Ohio Div of Geological Survey, Columbus, OH.

Totten SM. 1987. Glacial geology of Crawford County, Ohio [Unpubl manuscript]. Available from: Ohio Div of Geological Survey, Columbus, OH.

Totten SM. 1988a. Glacial geology of Hardin County, Ohio [Unpubl manuscript]. Available from: Ohio Div of Geological Survey, Columbus, OH.

Totten SM. 1988b. Glacial geology of Geauga County, Ohio. Columbus (OH): Ohio Div of Geological Survey Report of Investigations 140. 30 p.

Totten SM. 1989. Glacial geology of Lorain County, Ohio [Unpubl manuscript]. Available from: Ohio Div of Geological Survey, Columbus, OH.

Viani CW. 1986. Stratigraphy and mineralogy of tills in Knox County, Ohio [Unpubl MS thesis]. Akron (OH): Univ of Akron. 98 p.

Volpi RW, Szabo JP. 1988. Influence of local bedrock on the clay mineralogy of pre-Woodfordian tills of the Grand River lobe in Columbiana County, Ohio. Ohio J Sci 88:174-80.

White GW. 1982. Pleistocene geology of northeastern Ohio. Columbus (OH): Div of Geological Survey Bulletin 68. 75 p.

Willman HB, Glass HD, Frye JC. 1966. Mineralogy of glacial tills and their weathering profiles in Illinois, Part II. Weathering profiles. Urbana (IL): Illinois State Geological Survey Circular 400. 76 p.